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The Effect of Urban Forests on Air Quality and Human Health

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The Effect of Urban Forests on Air Quality and Human Health

by

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Abstract:

Following the industrial revolution, the impacts of climate change have been increasingly impactful on both rural and urban populations around the world. As population density and urbanization increase throughout the globe, the influences of climate change will continue to play a dangerous role in its influence on people's lives. Due to negative health impacts on humans and the economic costs in cities, climate change is one of the most important issues to understand in the 21st century. Air quality and human health are two components of climate change that are impacted most significantly. The bulk of this work is to understand the influence that urban forests have on air quality and human health in relation to urban forests and to highlight the importance of the species composition within them. Much of the existing research fails to highlight many of the critical factors involved in determining the effectiveness of urban forests in providing ecosystem services, including purifying air and water, reducing the urban heat island effect, increasing property values, and numerous other important benefits. Using a systematic literature review of existing information and a case study on the land cover composition of New York City us i-Tree Canopy this study will be able to benefit our understanding of how urban forests influence society. The host of benefits provided by the literature review and the case study will be able to improve the understanding that we have on how urban forests effectively provide numerous different ecosystem services, including the improvement of air quality and human health.

Introduction:

The purpose of this research is to explore the benefits of urban forests on pollution abatement and human health impacts; By identifying and analyzing the factors that make certain plants better suited for urban/ semi-urban environments it can be easier to understand the degree to which these species provide ecosystem services. It's important to understand the cost benefit analysis of urban vegetation in order to more effectively manage these environments. Urban forestry has been an increasingly popular field of study and practice since the term was coined in 1965. As the years have progressed our understanding of the benefits provided by trees in urban areas has also increased significantly. It is relatively unknown at this point in time, how much trees actually contribute to pollution abatement, combating climate change, and improving human health; I hope to further our understanding of how urban forests can help mitigate some of the effects of climate change, as it's going to be an increasingly persistent issue in the coming decades. Once that has been addressed this study can delve into which species of trees are best suited for urban forests to improve air and water quality to the highest degree.

In the wake of this increased GHG production, climate change has continued to negatively impact the environment throughout the 21st century. Rapid industrialization and urbanization along with continuous burning of fossils will continue to negatively impact the climate if society doesn't take action for preventing climate change. Global atmospheric CO_2 concentrations are predicted to potentially approach 800 million parts per million and temperatures could rise anywhere from 1.7° - 4°C (Dobbins et al, 2015).

The effects of climate change are already in motion, expected to be observable over the next several decades due to the persistent and drawn out nature of climate change. Even if emission production were to immediately stop, the current atmospheric GHG concentrations, being so much greater than natural levels, would continue to perpetuate large scale climate changes; Proactively curbing emission production and reducing other anthropogenic influences are some of the only ways to combat the effects of climate change (Corell, 2006). Urban forests present a unique opportunity to address these climatic influences.

It is also predicted that the frequency and severity of heat waves are going to increase, thus increasing heat/ drought stress within cities and increased O3 release, to add to this higher temperatures also affect growing seasons by making them longer (Dobbins et al, 2015). Budding, stem elongation, and flowering of plants is accelerated in the Spring due to higher air temperatures; In Autumn, the increased air temperatures can result in leaves falling off much later than normal unless premature senescence is caused by the climate (Dobbins et al, 2015).

The means to address climate change has been a hot button issue for the past several decades. The means to address climate change is debated equally as much if not more than how it will affect the world and how humans contribute to it. Expanding global trade and economic gains have perpetually influenced climate change throughout history and many nations put the environment second behind making money and expanding their GDPs. There is a general consensus that pollutants affect the area where they are emitted most severely but greenhouse gases are known to spread evenly throughout the atmosphere and subsequently affect the entire planet (Dobbins, 2015). The United states, China, Japan, India, the EU, Russia produce close to ⅔ of GHG emissions; China alone produces nearly 25% of GHGs and the United states produce around 16% of the world's GHGs (Dobbins, 2015).

One objective for my research is to determine the level of benefit that urban forests provide in terms of pollution abatement and human health benefits, and then to discuss the ways in which urban forestry programs are implemented. Once thes benefits have been discussed I hope to determine the scale of these influences, whether it's larger than an individual city scale or if it's localized to a single city or urban area. I then plan to address which genera or species of tree are most suited for providing ecosystem benefits in urban environments because Urban forests have been shown to have a qualitative and quantitative effect on purifying air and water supplies in urban ecosystems. In a field study conducted by Jun Yang, Joe McBride, Jinxing Zhou, Zhenyuan Sun urban forest areas of Beijing were mapped out and analyzed to determine the quantity of pollution removed from the air, as well as the amount of stored and sequestered carbon in Beijing's urban forests. In this study they concluded that trees and urban forests in general can mitigate air pollution in two different ways, either by directly reducing pollution or indirectly reducing emissions (Yang et al., 2005). Trees directly reduce pollution by absorbing gases like sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3) through the stomata in leaves and by dissolving water soluble pollutants on moist leaf surfaces (Yang et al., 2005). This study is very important to my research questions because it addresses the quantitative and qualitative benefits of the urban forests in a heavily polluted area but it also addresses that Populus, Robinia and Salix are the most abundant genera in the area of study; and have high BVOC emission rates. These genera are fast growing and have relatively short life spans; The CO2 fixed wood biomass in these genera will be released back to the atmosphere sooner than it would if trees known for longevity, such as Juniperus spp. were planted (Yang et al. 2005). These species-specific characteristics are a crucial aspect in furthering our understanding as to how much influence urban forests actually have on ambient air quality, among other ecological systems.

In a similar study conducted by Rüdiger Grote, Roeland Samson, Rocío Alonso, Jorge Humberto Amorim, Paloma Cariñanos, Galina Churkina, Silvano Fares, Didier Le Thiec, Ülo Niinemets, Teis Norgaard Mikkelsen, Elena Paoletti, Abhishek Tiwary and Carlo Calfapietra, air pollution mitigation potential for various species of trees is discussed. By analyzing the prevalence of different tree species in the location of study, and then comparing the characteristics that either positively or negatively impact said species ability to mitigate pollution, we can better understand which species are more or less beneficial for pollution abatement and sequestration. This study goes on to discuss that the overwhelming majority of gaseous and particle deposition occurs on the leaf surface, typically when the stomata are closed and the flow of atmosphere is restricted by physical barriers in the leaf's anatomy; There is a positive correlation between the complexity of leaf structure on particle deposition, as well as the presence of hairs and waxes on the leaf surface (Grote et al., 2016).

Leaf wettability plays a considerable role in the ability of particulate matter to be deposited on leaves because significant amounts of particulate matter can be sequestered by reactions with wet surfaces, which only increases with the presence of waxes, salts, and ions (Grote et al., 2016). Particulates may be encapsulated and immobilized within this wax layer; For pollutants such as nitrogen dioxide (N02) or sulfur dioxide (S02), they are water soluble, allowing direct dissolution in a watery film on the plant surface as well (Grote et al., 2016). Pollutant uptake through plant stomata is generally high, but only in the instances where the compounds are quickly removed from within the intercellular spaces, in the case of ozone and nitrogen oxides, they're almost immediately metabolized which implies their uptake will increase as atmospheric concentrations around the tree increase (Grote et al., 2016).

Another critical aspect of this research is to determine how urban forests improve human health and improve the overall quality of urban environments for other biotic and abiotic components. In a study conducted by David J. Nowak and Gordon M. Heisler, it was stated that many studies that correlate air pollution with adverse human health effects, but in relation to trees a lot of research has been done to investigate the degree that trees remove concentrations of pollution, but they often overlook the impact on human health in regards to pollution abatement and sequestration (Nowak & Heisler, 2010). Through a quantitative and qualitative correlational study, this research explores the impacts of urban trees in parks and how they impact UV light exposure, air quality and temperatures, the urban heat island effect, as well as energy cost savings in local communities. This study is particularly important for my research because it takes into account the ecosystem benefits of urban trees as well as total canopy cover in particular areas, but it also addresses the human health impacts, and quantifies the cost saving aspects in terms of energy and pollution production. One particularly significant benefit of urban forests is providing a shade from the canopy cover in public spaces. Ultraviolet radiation has unique properties due to its short wavelength, recommendations regarding UV radiation varies between experts but the general consensus is that prolonged exposure to these forms of sun burning radiation should be avoided and that shade from trees can significantly decrease it. (Nowak & Heisler, 2010). Lastly, this paper also notes the importance of species selection when considering trees for urban forests, as well as potential complications with the upkeep of said trees. The emissions from tree maintenance activities, combined with BVOC emission rates of trees can contribute to the formation of ozone, impact the microclimate of an area, and result in an overall increase in pollution emission if the best species aren't selected for an area (Nowak & Heisler, 2010).

In a literature review conducted by Stephanie Pincetl, Thomas Gillespie, Diane E. Pataki, Sassan Saatchi and Jean Daniel Saphores, an analysis of social systems, particularly urban forestry programs, and the subsequent local impacts was done. In this literature review and meta-analysis they focused on answering these six specific questions:

> "1 . What is the water cost of urban forests? 2. What is the carbon benefit of the urban forest? 3. Do trees increase property values? 4. Do trees provide a cooling benefit? 5. How has tree cover changed over time? 6. How was tree planting implemented? (Pincetl et al, 2012)."

This particular study is important to my research because it cross references the costs and benefits of urban forestry in both qualitative and quantitative respects. This study also delves into the process of engaging with community planners and government organizations to implement tree planting programs. It is important to note that trees and urban forests have positive health effects by fostering a connection with nature and beautifying neighborhoods (Pincetel et al. 2012). A connection between people and nature has shown positive impacts on human mental health by decreasing levels of anxiety (Pincetel et al. 2012). Although, it is also critical to understand the means by which these urban forests were created and implemented on a local scale. Notably, in the US: New York, Los Angeles, and Chicago have implemented urban forestry programs because of the multiple environmental and health benefits that may result from it (Pincetel et al., 2012). It has yet to be fully understood how to properly implement urban forests into existing infrastructure and framework in cities. Existing questions include how these programs can be effectively implemented by city governments and infrastructure management, how to pay for planting and maintenance, and the level of coordination between nonprofit organizations, the public, and private agencies at all levels to be successful (Pincetel et al., 2012).

In a meta-analysis conducted by Eric K. Arnold, he looks to understand the health impacts of climate change, specifically the urban heat island effect in relation to local communities in Oakland California. Urban forests make areas less high risk for heat related health risks. A lack of tree canopy cover exacerbates the risk of heat risk-related land cover, also known as the urban heat island effect; A heat island is an area where concrete, asphalt, roofing, and other impervious surfaces reflect significant amounts of heat that can increase temperatures by as much as 20 degrees Fahrenheit due to their heat capacity, thermal conductivity, and low reflectance of solar radiation (Arnold, 2015). With climate change increasing average global temperatures, urban populations increasing in size, and the urban heat island effect being the worst during summer time when overall energy demands increase, there is increased abundance of sulfur dioxide, nitrogen oxides, carbon monoxide, ground-level ozone, particulate matter, acid rain, and cases of heat stroke (Arnold, 2015).

In a literature review and comparative analysis of qualitative data Yendle Barwise and Prashant Kumar examine the qualitative impacts of urban forest mainly on air quality, although it is carefully cross referenced with species specific characteristics. Effective species selection for air pollution abatement requires a comprehensive understanding of the positive and negative aspects of different species phenology and morphology (Barwise & Kumar, 2020). This study is particularly important to my research because it highlights the specific characteristics of different species as it relates to their ability to positively or negatively impact levels of pollution as well as ambient air quality. It's also important to note that vegetation for the direct removal of certain pollutants at a city scale is considered negligible (Barwise & Kumar, 2020). Vegetation is a poor sink for many gaseous pollutants like nitrogen dioxide because it only occurs via stomatal uptake, nitric acid mitigation is also fairly poor because of the NO emission rates from vegetated soils compared to bare soils (Barwise & Kumar, 2020). On a local scale, pollution exposure reduction is well supported when it involves a vegetation barrier that physically separates the source of pollution from the receptor (Barwise & Kumar, 2020).

In a field study conducted by Akihiro Nakamura, Roger L. Kitching, Min Cao, Thomas J. Creedy, Tom M. Fayle, Martin Freiberg, C.N. Hewitt, Takao Itioka, Lian Pin Koh, Keping Ma, Yadvinder Malhi, Andrew Mitchell, Vojtech Novotny, Claire M.P. Ozanne, Liang Song, Han Wang, and Louise A. Ashton, it was determined that the effects of BVOCs have numerous effects on the atmosphere. Influencing the oxidative capacity of the atmosphere, the formation of ground level ozone, and the formation of aerosol particles are all affected by BVOCs produced by plants but these influences are poorly understood and lack existing research (Nakamura et al, 2017). The information and research regarding the atmospheric chemistry of BVOCs is improving however this research indicates that there are significant emissions of benzenoids from urban forests which are similarly impactful to that of anthropogenic sources of pollution (Nakamura et al, 2017). This research also helps support the consensus that there are many uncertainties and gaps in existing knowledge of the effect of BVOCs and the role of specific tree species (Nakamura et al, 2017).

In a literature review and meta analysis by : Elena L. Zvereva, Marja Roitto and Mikhail V. Kozlov they analyzed studies conducted on measuring the impact of pollution on plant life. They focused solely on studies that observed vegetation located near point sources of pollution, such as an individual factory. It's important to note they also excluded plants located in polluted environments when the impact zones of polluters did not overlap. Another criteria is that the pollution had influenced the adjacent habitats primarily through ambient air. Finally they looked only at plants that naturally inhabited the area of interest and they made sure to analyze both plants that were impacted and non-impacted to allow for cross comparison. This study is important to my research because it's useful to know how plants are impacted by pollution in our increasingly changing climate. As time progresses pollution will only continue to negatively impact plants even more.

The overall effect of air pollution on plant performance was negative, with variations of plant responses to the different kinds of pollution; Growth and reproduction of plants were each shown to be reduced to a similar extent (Zvereva & Kozlov, 2010) In general, plants affected by pollution had shorter annual roots and smaller leaves than plants in unpolluted environments however the number of leaves was not negatively impacted except in woody plants (Zvereva & Kozlov, 2010).

Each of these studies have important implications in my research because they explore qualitative or quantitative costs and benefits of urban forests. Understanding the degree and scale that urban forests have on pollution abatement, human health impacts, and energy savings can be achieved through careful analysis of existing data and potential experimentation of my own. By focusing my research on characteristics of different tree species, I will be able to develop a concise understanding of which trees are best suited for increasing ambient air quality, improving human health, and counteracting climate change. It will also be important to develop our understanding of which tree species are best suited for sequestering and storing carbon and other greenhouse gasses and pollutants.

The main goals of this research is to highlight the degree that urban forests provide ecosystem services for their surrounding communities and to identify discrepancies and gaps in existing knowledge and research. By analyzing the existing body of research that exists the influence of urban forests on air quality/pollution and human health benefits can be further determined. The other primary goal is to be able to make determinations about which species of trees are best suited for benefiting air quality and human health.

Methods:

The methodology of this research includes conducting a literature review and then conducting a case study by creating a map of New York Cities urban areas. This map will display the various cover types of 1000 randomly generated points within New York City. The cover types will include: Tree/shrub, grass/herbaceous, impervious buildings, impervious other, impervious road, soil/bare ground, and water. This will be done by randomly generating points and then labeling/identifying what kind of cover type is being represented. Once the points have been mapped out, the ecosystem services provided by the urban trees can be calculated. These benefits will show the total weight of carbon sequestered and stored in trees as well as the associated cost savings. The total weight of air pollution removed and the associated cost savings will also be determined; The air pollutants evaluated will include: carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, particulate matter less than 2.5 microns, and lastly particulate matter greater than 2.5 microns and less than 10 microns. This case study will be able to calculate the hydrological benefits of urban trees in terms of avoided runoff, evaporation, interception, transpiration, potential evaporation, and potential evapotranspiration.

The systematic literature review of existing research regarding the impacts of urban forests on air quality and human health will focus on highlighting consensuses, disagreements, and gaps in existing knowledge. With this study it will be possible to highlight the current state of existing knowledge pertaining to these concepts. By analyzing qualitative, quantitative, and mixed method studies related to the effects of urban forests on the earlier described factors, a greater breadth of information can be gathered and cross referenced; In doing so, this study will contribute to the existing body of research across numerous different countries in regards to the effect of urban forests on air quality and human health.

At present, vegetation is known to shape terrestrial ecosystems and play a vital role in the biosphere; The physiological and economic importance of the increasingly degraded and polluted plant communities has become an increasingly pertinent topic for the scientific and public communities (Zvereva & Kozlov, 2010). Due to the persistent nature of climate change as a result of increased atmospheric greenhouse gas concentrations, as well as, air and water pollution all from manmade sources, this issue is particularly important to understand quickly in order to properly manage it. By first analyzing the existing research regarding the degree that urban forests influence on air pollution and human health. it will be easier to identify which areas of focus in terms of qualitative and quantitative data need to be better understood in the coming future. This study will use a descriptive approach to highlight the current state of existing knowledge regarding the qualitative effects of urban forests on air quality and human health. Then using descriptive and correlative analysis to describe the degree that the quantitative data, pertaining to these factors, line up with existing qualitative information.

Once I have highlighted the influence that urban forests have on the earlier described benefits overall, this study can then move to focus on the species specific characteristics of different trees that make them more or less suited to positively influence the various benefits of urban forests. Through thematic analysis of morphological and vegetative characteristics it can then be identified where the consistencies, discrepancies, and gaps in existing knowledge occur regarding which species are best suited for planting in urban forests and positively impacting various ecosystem services.

Using the i-tree canopy cover modeling program I will be able to highlight the impacts of New York Cities urban forests on various ecosystem services and their respective economic benefits associated with urban trees. By identifying the locations of trees/shrubs, grasses/herbaceous plants, impervious buildings, impervious roads, other impervious surfaces, water, and bare ground/soil the ecosystem services can be understood more precisely.

Results:

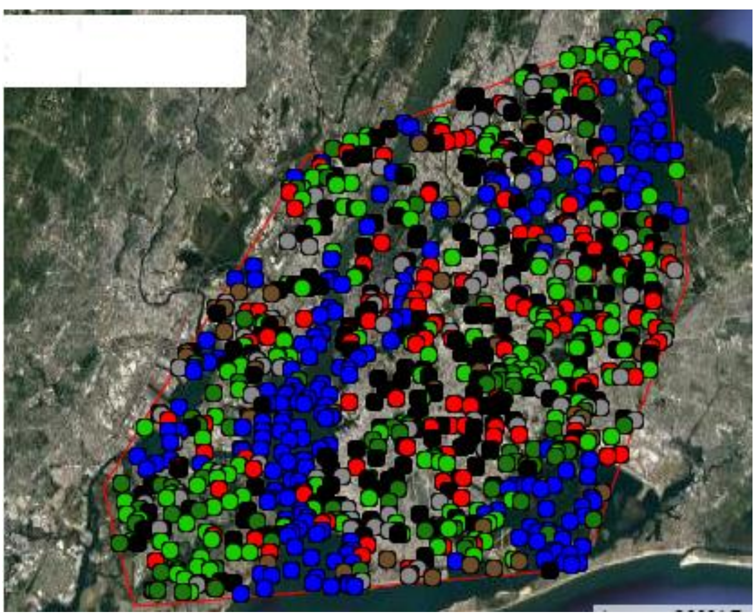

Figure 1: i-Tree Map of NYC Cover Types

Abbr.	Cover Class	Description	Points	% Cover ± SE	Area (mi²) ± SE
H	Grass/Herbaceous		92	9.20 ± 0.91	32.62 ± 3.24
IB	Impervious Buildings		236	23.60 ± 1.34	83.67 ± 4.76
IO	Impervious Other		93	9.30 ± 0.92	32.97 ± 3.26
IR	Impervious Road		128	12.80 ± 1.06	45.38 ± 3.75
S	Soil/Bare Ground		49	4.90 ± 0.68	17.37 ± 2.42
T	Tree/Shrub		183	18.30 ± 1.22	64.88 ± 4.34
W	Water		219	21.90 ± 1.31	77.64 ± 4.64
Total			**1000**	**100.00**	**354.54**

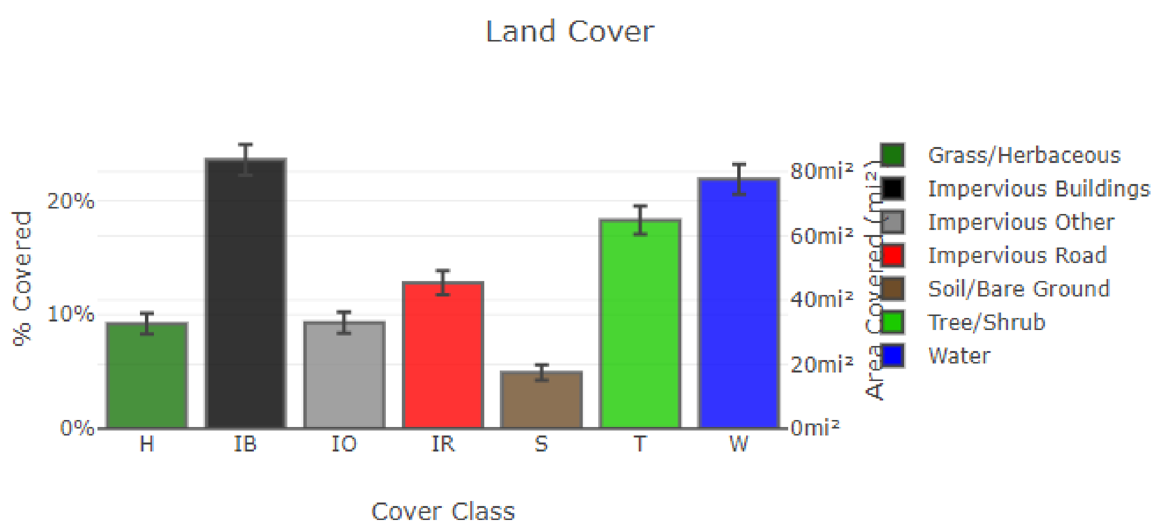

Figure 2: Graph of Land Cover Classes

Tree Benefit Estimates: Carbon (English units)

Description	Carbon (kT)	±SE	CO_2 Equiv. (kT)	±SE	Value (USD)	±SE
Sequestered annually in trees	44.46	±2.97	163.01	±10.89	$7,582,042	±506,608
Stored in trees (Note: this benefit is not an annual rate)	1,423.49	±95.11	5,219.46	±348.75	$242,777,236	±16,221,591

Currency is in USD and rounded. Standard errors of removal and benefit amounts are based on standard errors of sampled and classified points. Amount sequestered is based on 0.685 kT of Carbon, or 2.512 kT of CO_2, per mi^2/yr and rounded. Amount stored is based on 21.940 kT of Carbon, or 80.446 kT of CO_2, per mi^2 and rounded. Value (USD) is based on $170,550.73/kT of Carbon, or $46,513.84/kT of CO_2 and rounded. (English units: kT = kilotons (1,000 tons), mi^2 = square miles)

Figure 3: Tree Carbon Benefits

Tree Benefit Estimates: Air Pollution (English units)

Abbr.	Description	Amount (T)	±SE	Value (USD)	±SE
CO	Carbon Monoxide removed annually	29.79	±1.99	$39,725	±2,654
NO2	Nitrogen Dioxide removed annually	302.67	±20.22	$1,976,455	±132,060
O3	Ozone removed annually	822.10	±54.93	$47,608,472	±3,181,044
SO2	Sulfur Dioxide removed annually	174.77	±11.68	$412,213	±27,543
PM2.5	Particulate Matter less than 2.5 microns removed annually	58.94	±3.94	$205,987,425	±13,763,415
PM10*	Particulate Matter greater than 2.5 microns and less than 10 microns removed annually	467.96	±31.27	$2,933,371	±195,998
Total		**1,856.23**	**±124.03**	**$258,957,660**	**±17,302,715**

Currency is in USD and rounded. Standard errors of removal and benefit amounts are based on standard errors of sampled and classified points. Air Pollution Estimates are based on these values in T/mi²/yr @ $/T/yr and rounded:
CO 0.459 @ $1,333.50 | NO2 4.665 @ $6,530.02 | O3 12.671 @ $57,910.57 | SO2 2.694 @ $2,358.60 | PM2.5 0.908 @ $3,494,873.86 | PM10* 7.213 @ $6,268.44 (English units: T = tons (2,000 pounds), mi² = square miles)

Figure 4: Tree Air Pollution Benefits

Tree Benefit Estimates: Hydrological (English units)

Abbr.	Benefit	Amount (Mgal)	±SE	Value (USD)	±SE
AVRO	Avoided Runoff	1,691.51	±113.02	$15,115,340	±1,009,958
E	Evaporation	2,907.59	±194.28	N/A	N/A
I	Interception	2,908.79	±194.36	N/A	N/A
T	Transpiration	7,852.03	±524.65	N/A	N/A
PE	Potential Evaporation	31,863.06	±2,128.99	N/A	N/A
PET	Potential Evapotranspiration	24,485.61	±1,636.05	N/A	N/A

Currency is in USD and rounded. Standard errors of removal and benefit amounts are based on standard errors of sampled and classified points. Hydrological Estimates are based on these values in Mgal/mi²/yr @ $/Mgal/yr and rounded:
AVRO 26.071 @ $8,936.00 | E 44.814 @ N/A | I 44.832 @ N/A | T 121.022 @ N/A | PE 491.098 @ N/A | PET 377.391 @ N/A (English units: Mgal = millions of gallons, mi² = square miles)

Figure 5: Tree Hydrological Benefits

From the case study conducted on New York City's ecosystem services, out of the 1000 different cover types analyzed, 236 points (23.60%) are impervious buildings, 93 points (9.30%) are impervious other, 128 points (12.80%) are impervious roads, 219 points (21.90%) are water, 49 points (4.90%) are soil/bare ground, 92 points (9.20%) are grass/herbaceous, and 183 points (18.30%) are tree/shrub.

From the existing research there seems to be a strong consensus that trees improve air and water quality in numerous different ways and provide numerous ecosystem services, including improving human health; It's also worth noting that urban forests also reduce the urban heat island effect, reducing energy costs and providing cities with economic benefits from avoided emissions (Nitoslawski et al, 2016). The size of leaves, the shapes of canopies, the health, and maturity of trees are all important considerations to acknowledge in regards to the aforementioned ecosystem services.

Furthermore, the results of this case study reveal that 44.46 kilotons of carbon is sequestered annually which is equivalent to 163.01 kilotons of CO2 and that gas sequestration in this area saves the city approximately $7,582,042. The carbon stored in trees is approximately 1,423.49 kilotons which is equivalent to 5,219.46 kilotons of CO2 which saves the city approximately $242,777,236 in total.

These trees in New York also annually remove 29.79 tons of carbon monoxide which is valued at $39,725. Annually 302.67 tons of nitrogen dioxide is removed, valued at $1,976,455. There is 822.10 tons of ozone removed annually, valued at $47,608,472. The amount of particulate matter less than 2.5 microns removed annually is 58.94 tons, valued at $205,987,425. Particulate matter greater than 2.5 microns and less than 10 microns that's removed annually is 467.96 tons valued at $2,933,971. In total 1,856.23 tons of air pollution is removed annually, valued at $258,957,660.

The annual amount of avoided runoff is 1,691.51 Mgal/mi^2/yr per square mile per year which is valued at $15,115,340. The amount of evaporation is 2,907.59 Mgal/mi^2/yr. The amount of interception is 2,908.79 Mgal/mi^2/yr. The amount of transpiration is 7,852.03 Mgal/mi^2/yr. The Amount of potential evaporation is 31,863.06 Mgal/mi^2/yr. The amount of potential evapotranspiration is 24,485.61 Mgal/mi^2/yr.

From the systematic literature review with the results of this case study in mind, in order to determine the best suited species for urban environments, we must consider the results of the literature review. Several genera of trees are primary sources of isoprene, such as, trees in the genus Populus, Salix, and Plantanus; The genus Quercus, Malus, and Pinus were shown to be primary sources of producing monoterpenes (Barwise & Kumar, 2020). In addition to this in semi-natural and urban environments the genus Betula was shown to have very high BVOC emission rates; The particular species is a very critical consideration to observe when looking at the contribution to air pollution and human health.

In terms of which species are best suited for urban forests, out of some of them more common urban tree species in the U.S., Quercus rubra, Quercus robur, Quercus petreae, Salix alba, Salix caprea, Salix fragilis, and Populus tremula are considered to be very high isoprene emitters; Species that are most beneficial to air quality, due to their low emissions of isoprene, include Pinus nigra, Prunus laurocerasus, Larix decidua, Crategus monogyna, Chamaecyparis lawsoniana, Betula pendula, Alnus glutinosa, Acer plantanoides, and Acer campestre, however it's important to not that Pinus nigra is a particular significant emitter of monoterpenes (Barwise et al. 2020).

Healthy trees with a DBH greater than 77 centimeters remove close to 70 times the amount of air pollution than healthy trees with DBH less than 8 centimeters (Dobbins et al, 2015). Air quality improvements generally occur during the daytime in most locations; In New York City, during the daytime of the on-leaf season, generally remove 0.47% of particulate matter, 0.45% of the ozone, 0.43% of sulfur dioxide, 0.30% of the nitrogen dioxide, and lastly 0.002% of carbon monoxide (Dobbins et al, 2015). The percent of air canopy cover at various different heights is shown to improve air quality within urban ecosystems; Comparatively in natural forest stands with total canopy cover, this study concluded that pollution removal in 1 hour, is as high as 15% of the ozone removed, 14% of the sulfur dioxide, 13% of the particulate matter, 8% of nitrogen dioxide, and lastly 0.05% of the carbon monoxide sequestered (Dobbins et al, 2015) .

The emission rates of VOCs and BVOCs can vary extremely significantly from one species or another but this study also concludes that these 9 genera have very high levels of isoprene emissions; willows (Salix spp.), black locust (Robinia spp.), oak (Quercus spp.), poplar (Populus spp.), sycamore (Platanus spp.), black gum (Nyssa spp.), sweetgum (Liquidambar spp.), Eucalyptus spp., and beefwood (Casuarina spp.); The high VOC emission rates of these plants can significantly contribute to the formation of ozone as well as CO (Dobbins et al, 2015). One important consideration that was concluded by this study is that regions with low NO3 levels in many cases can have ozone removed by these particular trees; Considering that temperature is another extremely influential factor in pollution emission, increasing tree canopy cover can reduce air temperatures while also reducing the amount of pollution that is formed and sequestered (Dobbins et al, 2015). The overall influence of trees' VOC emissions on urban ecosystems' pollution levels is a particularly important area of research to understand and embodies a significant gap in existing research overall.

The use of fossil fuels in transportation, maintenance, and management can be a significant source of pollution, due to the types of machinery and equipment used, also considering the effects of fossil fuels on the atmosphere and pollution in cities. This means that the large inputs of fossil fuels in transportation and long term maintenance are an extremely important factor for urban greenspace planners and managers to consider in their afforestation efforts. Brooklyn in New York City has several common genera of trees that are rather effective in lowering the ozone and pollution levels in cities; honey locust (Gleditsia sp.), linden (Tilia spp.), cherry (Prunus spp.), mulberry (Morus spp.). Shade provided by urban trees helps reduce the energy outputs and needs for vehicles and buildings while also improving human health in numerous ways.

Discussion:

In general, the lengths of growing seasons within urban areas are increasing in length due to the heat island effect, compared to rural areas (Barwise et al, 2020). There is an apparent consensus among existing research that BVOC emissions are expected to increase with the increasing temperatures and $CO2$ levels of climate change (Barwise et al, 2020). The existing body of research indicates that drought has significant influences on the stomatal conductance of plants in response to higher levels of $CO2$; Drought response in plants is known to induce leaf shedding, decreases in leaf size, increasing leaf thickness and wax abundance (Grote et al, 2016). The increases in leaf thickness and the presence of wax on leaves is most likely a biological response to make the plants more suitable/capable of surviving in increasingly polluted environments.

Existing research also seems to show consensus that pollen viability decreases with the rising levels of air pollution; $O3$ is one agent that positively correlates with the increasing allergenicity of pollen (Nakamura et al, 2017). Air pollution is positively correlated with allergen toxicity in existing research (Grote et al, 2016). Another important consideration that existing research shows is that high $O3$ concentrations also decrease the levels of photosynthesis and stomatal conductance, which decrease a plant's ability to withstand stress from droughts; BVOC emissions are shown to increase under $O3$ exposure (Grote et al, 2016). In addition to this, existing research shows that CO affects the physiological processes of plants including dormancy, stomatal closure, seed dormancy, and regulational ability in response to environmental stressors (Grote et al, 2016).

A consensus exists in that the changing geographic ranges of different tree species will lead to an increased abundance of “new” tree species in the areas of increasing temperatures, mostly of trees that are adapted to warmer conditions (Nakamura et al, 2017). Newly introduced tree species that aren’t native to a particular region will have varied effects on the ability of them to contribute to the ecosystem services of urban forests, which will have important implications on the persistently changing climate of the 21st century including patterns in leaf longevity, allergenicity, and BVOC emission rates and/or reactivity (Nakamura et al, 2017).

Considering the atmospheric reactivity of many BVOC’s being higher than that of similar carbon anthropogenic VOCs, the type of BVOC emitted is just as important to consider as the total amount released (Barwise & Kumar, 2020). There is consistent agreement in existing research that the highest priority should be given to BVOCs that have higher reactivity, especially near road environments (Barwise & Kumar, 2020). Existing research lends to the fact that BVOCs on the global scale are significantly influenced by anthropogenic environmental changes, which disturb the relationship between the biosphere and atmosphere resulting in increased amounts of BVOCs being produced (Barwise et al. 2020). It is critically important to understand the air quality influences of plants, the contribution, in general and in terms of BVOC release, impacting local air pollution concentrations is largely determined by the age, health, size, species, and spatial location of urban forests (Grote et al,2016).

Pinus species tend to be favored in southern Europe, because they are efficient at removing pollution and are relatively stress tolerant; in particular, they are drought resistant, a trait that is comparatively less relevant in Northern regions (Miller et al., 2015). This is an important consideration around the world and the United States is no exception. Stress tolerance may be one of the first selection criteria in areas that are polluted, even if the gain in ecosystem services is not all that significant. Ecosystem services are often indirectly related to each other; One particularly important example of this in the existing body of research shows that ecosystem services that cool the microclimate of an area help to reduce energy consumption and decrease the anthropogenic emissions of GHGs (Grote et al, 2016). This is one of the many examples of areas of research that need to be studied further in order to fully develop our understanding of its influences from urban forests, many of which are dependent on the particular species of trees. (Grote et al, 2016).

Conifers, specifically pines and cypresses offer some of the best pollution reduction in general; Due to the nature of deciduous trees, considering they don't lose their leaves, they are one some of the most impactful species on reducing pollution levels in various different environments, especially urban ecosystems. London plane, silver maple, honey locust are also consistently shown to be very beneficial in removing air pollution (Nakamura et al, 2017).

Consensus exists in that trees remove gaseous air pollutants primarily through their stomata, meaning that it occurs less at night while the stomata are closed, though some pollutants are removed via the plant surface (Nock et al, 2013). It's shown consistently from existing research that once gaseous pollutants, after they're inside the leaf, diffuse into the intercellular spaces of the leaves and can be absorbed by the water and films to form acids that react with inner leaf surfaces (Nock et al, 2013). Intercepting airborne particles is consistently one of the most notable ecosystem services provided by trees in urban environments, however it's important to note that most particles are retained on the plant surface and don't just disappear entirely.

Particulates can often be put back into the atmosphere from the wind, leaves falling, or by being washed off by rain, which consequently means that trees sometimes only provide a temporary benefit in removing pollution (Manes, 2012).

There is consensus that pollution rates differ among cities for numerous reasons; The amount of existing air pollution, climate, precipitation, and length of growing seasons are all important considerations when determining the best suited tree species for urban ecosystems (Manes, 2012). Research also shows consensus that since the late 19th century major warming periods have occurred between 1910 to 1945 and from 1976 to the present day, primarily caused by human fossil-fuel consumption and use, contributing significantly to the overall GHG levels within the atmosphere; Urban forests are known to be impactful storage sites for carbon dioxide (CO_2), which is the primary greenhouse gas (NYC Tree Map, 2019). Street trees/ urban forests specifically reduce atmospheric CO_2 in two ways: Directly sequestering CO_2 in their stems and leaves during growth and reducing the demand for heating and air conditioning in nearby buildings thereby reducing the CO_2 emissions from generating power for heating and cooling (NYC Tree Map, 2019).

Existing research consistently indicates that air pollution can have very serious health consequences for many people in urban environments, causing headaches, couching, asthma, respiratory and heart disease, as well as cancer (NYC Tree Map, 2019). Urban forests provide several main benefits, one of which is their ability to absorb gaseous pollutants such as, O_3, NO_2, SO_2, through leaf surfaces (Nowak, 2002). Another benefit is intercepting PM_{10} which includes dust, ash, pollen, and smoke; It is also known that oxygen is produced through photosynthesis (Nowak, 2002). Existing research agrees that water is transpired and surfaces are shaded by canopy cover which lowers air temperatures, thus reducing O_3 levels; Research shows that trees can directly reduce energy use, pollution from emissions from numerous sources is reduced including NO_2, SO_2, PM_{10}, and volatile organic compounds (VOCs) (Grote et al, 2016). Lastly urban forests decrease the amount of evaportative hydrocarbon emissions and O_3 formation by impervious surfaces, including parked cars by providing shade in urban landscapes (Rosenzweig, 2021). Polluted stormwater runoff is a significant source of pollution in streams, wetlands, lakes, and oceans, and healthy trees can significantly reduce the amount of pollution in the water and decrease the total volume of runoff (NYC Tree Map, 2019). Interception benefit is the amount of rainfall prevented from hitting the ground by the tree canopy that is then evaporated from the crown. The volume of runoff is thereby reduced and the peak flow of runoff is delayed and substantially reduced, thus improving water quality during small rainfall events that produce the most pollutant wash off. (NYC Tree Map, 2019).

There are many gaps in existing knowledge as to which species of trees are the most beneficial overall for contributing to pollution abatement and various other ecosystem services. For starters there are close to a hundred BVOCs that cause significant influences on the atmosphere however there is very limited information on most of the impactful BVOCs (Barwise & Kumar, 2020). There is very limited existing research on the rates of production and causes of numerous different BVOCs (aside from the two most abundant, isoprene and monoterpenes) as well as how they affect individual plant species ((Barwise & Kumar, 2020).

Summary & Conclusion:

This study was conducted in order to further the understanding of how urban forests influence air quality and human health. A systematic literature review was selected to be used to highlight the ecosystem services provided by urban trees and to develop our understanding of which tree species are most beneficial for urban environments while being able to identify gaps in existing knowledge. The case study on i-Tree canopy was used to highlight the distribution of urban greenspaces in New York City and to demonstrate the scale of the ecosystem services provided by urban forests in relation to the literature review. In doing so a great deal of information was revealed about the benefits connected to pollution sequestration and abatement, as well as, energy savings and human health benefits.

Some of the most important conclusions of this study include that maintaining existing canopy cover, combined with increasing the number of healthy trees provides an increase in the amount of pollution removed. Pollen allergenicity varies between species and requires more research in the future. The best kinds of trees to plant include larger and healthier trees, of which provide more benefits. Maintaining a diverse range of species, ages, and sizes is critically important in urban ecosystems. Maximizing trees that produce low levels of VOCs helps to reduce ozone, carbon monoxide, and other air pollutants which is another area of study that requires more study. Long-lived and slow-growing tree species are most beneficial due to the prolonged ability of them to be able to provide different ecosystem services. Trees that require less maintenance will be more beneficial in reducing the long term cost of maintenance and planting/removal needs. It's also important to consider reducing the fossil fuel production/use while conducting maintenance activities to benefit air quality and tree health. Planting trees in energy conserving locations, like next to buildings and roads, and regions that are more polluted, such as near power plants, will also provide more benefits in the long run.

This research has found that in future studies one of the most important areas of focus that needs further evaluation is the impact of some of the lesser known BVOCs. There will also need to be future research into species specific characteristics as well as which species are most beneficial to urban environments. There is little existing research and consensus regarding the degree that VOCs impact air pollution as well as which species are the best at sequestering and abatement of pollution in general. There are many consensus in existing research that indicate that trees sequester pollution, improve air quality, provide human health benefits, and improve energy savings.

The information collected in this study indicates urban forests have very significant benefits and provide countless ecosystem services. Understanding this is useful for city planners and urban greenspace managers in that the information is pertinent for maximizing the ecosystem services provided by urban forests. This research is also extremely beneficial in providing useful information that indicates there are significant gaps in existing knowledge about various factors involved in how urban forests influence air quality and human health. From the existing research this study has helped to determine the best species of trees to plant as well as qualities that make them particularly beneficial to providing ecosystem services in urban environments, improving air quality and human health.

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